

We claim:

- 1 1. A substrate comprising chromium and a gradient from an inside to an
2 outside surface consisting essentially of:
3 substrate molecules/a mixture of said substrate molecules and substrate-X
4 molecules comprising chromium-X/a surface comprising a sufficient
5 quantity of said chromium-X molecules to produce a final coefficient
6 of friction in an unlubricated condition against a steel counterface that
7 is less than a virgin coefficient of friction of said surface in the absence
8 of said gradient;
9 wherein X is selected from the group consisting of fluorine (F), oxygen (O),
10 and sulfur (S).
- 1 2. The substrate of claim 1 wherein X is F.
- 1 3. The substrate of claim 1 wherein X is S.
- 1 4. The substrate of claim 1 wherein said gradient further comprises
2 chromium carbide molecules.
- 1 5. The substrate of claim 2 wherein said gradient further comprises
2 chromium carbide molecules.
- 1 6. The substrate of claim 3 wherein said gradient further comprises
2 chromium carbide molecules.
- 1 7. The substrate of claim 1 comprising chromium-X molecules to a depth
2 of 50 nm or more from the outer surface of said substrate.
- 1 8. The substrate of claim 1 comprising chromium-X molecules to a depth
2 of 150 nm or more from the outer surface of said substrate.

1 9. The substrate of claim 1 comprising chromium-X molecules to a depth
2 of 250 nm or more from the outer surface of said substrate.

1 10. The substrate of claim 1 having a final hardness of about 15 GPa or
2 more.

1 11. The substrate of claim 1 having a final hardness of about 20 GPa or
2 more.

1 12. The substrate of claim 1 having a final hardness of about 25 GPa or
2 more.

1 13. The substrate of claim 1 wherein said final coefficient of friction is
2 about 0.3 or less.

1 14. The substrate of claim 1 wherein said final coefficient of friction is
2 about 0.2 or less.

1 15. The substrate of claim 1 wherein said final coefficient of friction is
2 about 0.1 or less.

1 16. The substrate of claim 10 wherein said final coefficient of friction is
2 about 0.3 or less.

1 17. The substrate of claim 10 wherein said final coefficient of friction is
2 about 0.2 or less.

1 18. The substrate of claim 10 wherein said final coefficient of friction is
2 about 0.1 or less.

1 19. The substrate of claim 11 wherein said final coefficient of friction is
2 about 0.3 or less.

1 20. The substrate of claim 11 wherein said final coefficient of friction is
2 about 0.2 or less.

1 21. The substrate of claim 11 wherein said final coefficient of friction is
2 about 0.1 or less.

1 22. The substrate of claim 12 wherein said final coefficient of friction is
2 about 0.3 or less.

1 23. The substrate of claim 12 wherein said final coefficient of friction is
2 about 0.2 or less.

1 24. The substrate of claim 12 wherein said final coefficient of friction is
2 about 0.1 or less.

1 25. The substrate of claim 1 wherein said substrate comprises a chromium
2 content and said sufficient quantity comprises from about 10 atomic % to about 40
3 atomic % oxygen.

1 26. The substrate of claim 1 wherein said substrate comprises a chromium
2 content and sufficient quantity comprises about 25 atomic % oxygen.

1 27. The substrate of claim 2 comprising chromium-fluorine molecules to a
2 depth of 50 nm or more from the outer surface of said substrate.

1 28. The substrate of claim 2 comprising chromium-fluorine molecules to a
2 depth of 150 nm or more from the outer surface of said substrate.

1 29. The substrate of claim 2 comprising chromium-fluorine molecules to a
2 depth of 250 nm or more from the outer surface of said substrate.

1 30. The substrate of claim 2 having a final hardness of about 15 GPa or
2 more.

1 31. The substrate of claim 2 having a final hardness of about 20 GPa or
2 more.

1 32. The substrate of claim 2 having a final hardness of about 25 GPa or
2 more.

1 33. The substrate of claim 2 wherein said final coefficient of friction is
2 about 0.3 or less.

1 34. The substrate of claim 2 wherein said final coefficient of friction is
2 about 0.2 or less.

1 35. The substrate of claim 2 wherein said final coefficient of friction is
2 about 0.1 or less.

1 36. The substrate of claim 2 wherein said substrate comprises a chromium
2 content and said sufficient quantity comprises from about 10 atomic % to about 40
3 atomic % F.

1 37. The substrate of claim 2 wherein said substrate comprises a chromium
2 content and said sufficient quantity comprises about 25 atomic % F.

1 38. The substrate of claim 3 comprising chromium-S molecules to a depth
2 of 50 nm or more from the outer surface of said substrate.

1 39. The substrate of claim 3 comprising chromium-S molecules to a depth
2 of 150 nm or more from the outer surface of said substrate.

1 40. The substrate of claim 3 comprising chromium-S molecules to a depth
2 of 250 nm or more from the outer surface of said substrate.

1 41. The substrate of claim 3 having a final hardness of about 15 GPa or
2 more.

1 42. The substrate of claim 3 having a final hardness of about 20 GPa or
2 more.

1 43. The substrate of claim 3 having a final hardness of about 25 GPa or
2 more.

1 44. The substrate of claim 3 wherein said final coefficient of friction is
2 about 0.3 or less.

1 45. The substrate of claim 3 wherein said final coefficient of friction is
2 about 0.2 or less.

1 46. The substrate of claim 3 wherein said final coefficient of friction is
2 about 0.1 or less.

1 47. The substrate of claim 41 wherein said final coefficient of friction is
2 about 0.3 or less.

1 48. The substrate of claim 41 wherein said final coefficient of friction is
2 about 0.2 or less.

1 49. The substrate of claim 41 wherein said final coefficient of friction is
2 about 0.1 or less.

1 50. The substrate of claim 42 wherein said final coefficient of friction is
2 about 0.3 or less.

1 51. The substrate of claim 42 wherein said final coefficient of friction is
2 about 0.2 or less.

1 52. The substrate of claim 42 wherein said final coefficient of friction is
2 about 0.1 or less.

1 53. The substrate of claim 43 wherein said final coefficient of friction is
2 about 0.3 or less.

1 54. The substrate of claim 43 wherein said final coefficient of friction is
2 about 0.2 or less.

1 55. The substrate of claim 43 wherein said final coefficient of friction is
2 about 0.1 or less.

1 56. The substrate of claim 3 wherein said substrate comprises a chromium
2 content and said sufficient quantity comprises from about 10 atomic % to about 40
3 atomic % S.

1 57. The substrate of claim 3 wherein said substrate comprises a chromium
2 content and said sufficient quantity comprises about 25 atomic % S.

1 58. A substrate comprising chromium and a gradient from an inside to an
2 outside surface consisting essentially of:

3 substrate molecules/a mixture of said substrate molecules and substrate-
4 oxygen (O) molecules comprising chromium-O/a surface comprising a
5 sufficient quantity of said chromium-O molecules to produce a final
6 coefficient of friction in an unlubricated condition against a steel
7 counterface that is less than a virgin coefficient of friction of said
8 surface in the absence of said gradient.

1 59. The substrate of claim 58 wherein said gradient further comprises
2 chromium carbide molecules.

1 60. The substrate of claim 58 comprising chromium-O molecules to a
2 depth of 50 nm or more from the outer surface of said substrate.

1 61. The substrate of claim 58 comprising chromium-O molecules to a
2 depth of 150 nm or more from the outer surface of said substrate.

1 62. The substrate of claim 58 comprising chromium-O molecules to a
2 depth of 250 nm or more from the outer surface of said substrate.

1 63. The substrate of claim 59 comprising chromium-O molecules to a
2 depth of 50 nm or more from the outer surface of said substrate.

1 64. The substrate of claim 59 comprising chromium-O molecules to a
2 depth of 150 nm or more from the outer surface of said substrate.

1 65. The substrate of claim 59 comprising chromium-O molecules to a
2 depth of 250 nm or more from the outer surface of said substrate.

1 66. The substrate of claim 58 having a final hardness of about 15 GPa or
2 more.

1 67. The substrate of claim 59 having a final hardness of about 15 GPa or
2 more.

1 68. The substrate of claim 65 having a final hardness of about 15 GPa or
2 more.

1 69. The substrate of claim 58 having a final hardness of about 20 GPa or
2 more.

1 70. The substrate of claim 59 having a final hardness of about 20 GPa or
2 more.

1 71. The substrate of claim 65 having a final hardness of about 20 GPa or
2 more.

1 72. The substrate of claim 58 having a final hardness of about 25 GPa or
2 more.

1 73. The substrate of claim 59 having a final hardness of about 25 GPa or
2 more.

1 74. The substrate of claim 65 having a final hardness of about 25 GPa or
2 more.

1 75. The substrate of claim 58 wherein said final coefficient of friction is
2 about 0.3 or less.

1 76. The substrate of claim 58 wherein said final coefficient of friction is
2 about 0.2 or less.

1 77. The substrate of claim 58 wherein said final coefficient of friction is
2 about 0.1 or less.

1 78. The substrate of claim 59 wherein said final coefficient of friction is
2 about 0.3 or less.

1 79. The substrate of claim 59 wherein said final coefficient of friction is
2 about 0.2 or less.

1 80. The substrate of claim 59 wherein said final coefficient of friction is
2 about 0.1 or less.

1 81. The substrate of claim 65 wherein said final coefficient of friction is
2 about 0.3 or less.

1 82. The substrate of claim 65 wherein said final coefficient of friction is
2 about 0.2 or less.

1 83. The substrate of claim 65 wherein said final coefficient of friction is
2 about 0.1 or less.

1 84. The substrate of claim 58 wherein said substrate comprises a
2 chromium content and said sufficient quantity comprises from about 10 atomic % to
3 about 40 atomic % oxygen.

1 85. The substrate of claim 58 wherein said substrate comprises a
2 chromium content and sufficient quantity comprises about 25 atomic % oxygen.

1 86. The substrate of claim 58 wherein said gradient from inside to an
2 outside surface consists essentially of chromium alloy molecules; a mixture
3 comprising chromium alloy molecules and chromium-O molecules; a surface
4 comprising a sufficient quantity of said chromium-O molecules to produce a final
5 coefficient of friction in an unlubricated condition against a steel counterface that is
6 less than a virgin coefficient of friction of said surface in the absence of said gradient.

1 87. The chromium alloy substrate of claim 86 wherein said gradient further
2 comprises chromium carbide molecules.

1 88. A substrate comprising a chromium coating comprising a gradient
2 from inside to an outside surface consisting essentially of:
3 primarily chromium molecules/a mixture of chromium oxide molecules and
4 chromium molecules/a surface comprising a sufficient quantity of said
5 chromium oxide molecules to produce a final coefficient of friction in
6 an unlubricated condition against a steel counterface that is less than a
7 virgin coefficient of friction of said surface in the absence of said
8 gradient.

1 89. The substrate of claim 88 wherein said gradient from inside to an
2 outside surface consists essentially of chromium alloy molecules; a mixture
3 comprising chromium alloy molecules and chromium oxide molecules; a surface
4 comprising a sufficient quantity of said chromium oxide molecules to produce a final
5 coefficient of friction in an unlubricated condition against a steel counterface that is
6 less than a virgin coefficient of friction of said surface in the absence of said gradient.

1 90. The substrate of claim 89 wherein said gradient further comprises
2 chromium carbide molecules.

1 91. The substrate of claim 89 wherein said gradient further comprises
2 chromium alloy molecules.

1 92. The substrate of claim 89 comprising an automotive component.

1 93. The substrate of claim 89 comprising an aeronautical component.

1 94. The substrate of claim 89 comprising a journal bearing.

1 95. The substrate of claim 89 comprising a tool for injection molding of
2 filled polymers.

1 96. The substrate of claim 89 wherein said tool is selected from the group
2 consisting of a plated mold and a runner block.

1 97. The substrate of claim 91 comprising a medical implant.

1 98. The medical implant of claim 97 wherein said gradient further
2 comprises chromium carbide molecules.

1 99. The medical implant of claim 97 comprising a total joint replacement.

1 100. The medical implant of claim 98 comprising a total joint replacement.